Library of Labs

A European Project on the Dissemination of Remote Experiments and Virtual Laboratories

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ABSTRACT

In this paper, we provide background information on the EC funded Lila Project ("Library of Labs"), describe its goals and purposes, provide some insight into its software design and provide first experiences, made at the University of Stuttgart using the eLearning content deployed by the project.

Keywords

Remote Experiment, Virtual Lab, Engineering Education.

1. Introduction

While traditional eLearning aims at the dissemination of "classical media", for example lecture notes, homework assignments, online assessments, or possibly even lecture recordings, the aim of the EC funded LiLa project is to integrate lab experiments into Learning Management Systems and build a repository of such experiments shared between universities in Europe and worldwide. While lab experiments are traditionally carried out in hands-on laboratories, LiLa [19] provides access to online experiments made available to students electronically over the internet. Even though the goal is certainly not to replace the training in hands-on labs, such online experiments can be used to enrich and extend the current means of teaching; they also provide the advantage of being accessible from almost anywhere, and being available almost any time. That is, lectures offering online experiments allow for greater flexibility, and make learning independent of the opening hours of the 's laboratory facilities.

Certainly, designing, installing and maintaining online labs is a challenge by itself, and a single university alone is likely not able to provide a pool of experiments rich enough to satisfy all the demands of the syllabus. To this end, the LiLa project collects such experiments on a European and also world-wide basis, makes such experiments available through an online portal that allows sharing and exchange of experiments, and offers lecturers the possibility to download these experiments into their courses, hosted by the Learing Management System of their homing institution.

Additionally, LiLa eases the development of new online experiments by providing a "booking system", that is, an online tool to control the reservation and availibility of scarce resources such as access to remotely controlled lab equipment.

To advance the dissemination and interoperability of online labs further, the University of Stuttgart as the head of the LiLa project is also a founding member of an international group of Universities that implement and specify such equipment. The long-term goal of the GOLC ("Global Online Laboratory Consortium") [1] can thus be understood as an internationalization of the LiLa ideas.
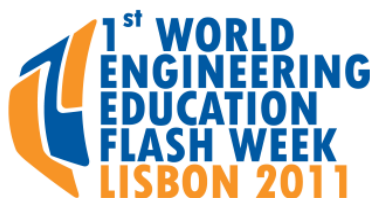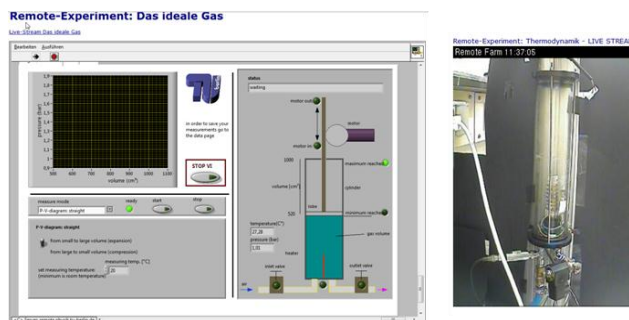

FIGURE 1: AN EXPERIMENT ON THE IDEAL GAS FROM THE REMOTE FARM OF THE TU BERLIN. LEFT: THE LABVIEW CONTROL PANEL. RIGHT: THE LIFE STREAM OF THE EXPERIMENT.

1.1 Related Initiatives

Conceptually, LiLa distinguishes between two types of online experiments: Remote Experiments and Virtual Laboratories. The former denotes real lab equipment made accessible over the internet by some type of remote access, the second being virtual simulations only performed by a computer algorithm. Both types have advantages and drawbacks, and are ideally combined in a lecture to broaden the students' insight [2]. The difference is of importance in so far as virtual experiments can be performed anytime by just running a computer algorithm on the machine of the learner (or a server), whereas remote experiments require access to scarce resources such as the lab equipment to be controlled remotely; as such, remote experiments, since they cannot be accessed simultaneously, require some kind of booking process that is offered by the LiLa infrastructure as a service.

Of course, LiLa is not the first project that aims at the dissemination of such online experiments: Probably the earliest and most prominent project in the same direction is the iLabs project [3] of the MIT; one of the advocated goals of the Australian LabShare project [4] is also the reduction of costs by sharing such labs. The Lab2Go project [5] finally aims at building an index of online labs and provides an ontology for classifying such experiments.

Nevertheless, there are some important differences between LiLa and these related projects that shall be explained in more detail in the following: Both iLabs and LabShare define a rigid software infrastructure for their laboratories. For iLabs, for example, the infrastructure is based on SOAP, requiring the interaction of service brokers, lab server and student machine to name only a couple of components. LiLa, however, does by itself **not** specify how a remote control of a laboratory shall be established. Instead, it defines a "meta-infrastructure" that instead describes packaging and dissemination of access mechanisms to online equipment in such a way that **any online lab using html to deliver its content to the user can be integrated into LiLa.** That is, LiLa defines a set of minimal interfaces sufficient to build a **repository** of labs without specifying their architecture completely, unlike what iLabs or LabShare do. The requirements on this architecture are driven by the desired use-cases explained in section 2, the interfaces itself are described in section 3. Roughly, LiLa is build around SCORM[6] for packaging, which basically provides online resources as "canned web pages" packaged with all required resources in a ZIP archive.

LiLa also differs from Lab2Go in several aspects: While both Lab2Go and LiLa aim at collecting online resources, Lab2Go provides **references** to online resources; whereas LiLa is an **online repository**, that is, also offers such resources for download from its web portal, and offers the possibility to reserve and book them through a unified web interface.

In short, LiLa is not a tight architecture as iLabs or LabShare is, but rather a framework that allows the easy integration of third-party resources. In fact, LabShare experiments have already been successfully integrated into LiLa, and the same goes for iLabs on a prototypical basis.

2. Use Cases

While the experiments made available through LiLa are, of course, targeted at *students* as users, the students themselves are not the primary user group of the web portal implementing the LiLa repository [19]. This might come surprising, but one should observe that the central access point for students reaching for learning material **is usally the Learning Management System** of their universities, and as such, access to any experiments they would want to perform has to go through this system. This not only eases the integration of experiments into existing online courses, it also offers a unique entry point for learners without breaking their established workflow.

Instead, *teachers* (or lecturers) use the LiLa portal to find and identify experiments they prefer to include in their courses, download such experiments from the LiLa portal, and upload them to the Learning Management System. To this end, LiLa offers such experiments in the form of SCORM packages that - almost any - Learning Management System (LMS) is able to accept and integrate.

The third user group is that of *content providers* which design, install, maintain, package and upload experiments into the LiLa portal. As for downloading, experiments must be prepared as SCORM packages for the upload, though the portal simplifies the process somewhat by collecting metadata itself instead of requiring users to fiddle them into the SCORM package. The upload process also, optionally, re-wraps the packages such that they become bookable resources and are only accessible if the underlying hardware has been reserved by the corresponding user.

This brings us to another important use-case for the LiLa portal, namely the reservation and booking of resources: While virtual laboratories are available all of the time, access to hardware resources requires that they are booked by the student. The details of this booking process is described in detail in section 5.

Besides booking, the *third* use case of the LiLa portal is that of locating, administrating and identifying content. Content is, for the purposes of the portal, not limited to experimental resources, it also includes learning material around such experiments; this includes lesson elements that embed experiments into a didactic content, and courses that sequence such elements. The purpose is not so much to re-implement the functionality of a learning management system, but to provide hints and use cases for teachers and lecturers how to optimally deploy the experiments; in our experience, see section 6, we found it vitally important to offer such help and support the teaching staff not only from a technical perspective.

As experiments and supporting material in the form of "traditional media" enter the portal, it is annotated by meta-data to facilitate searching and indexing. While meta-data can be partially automatically generated from data already available, as for example the name of the provider and the upload date, a meta-data editor with useful defaults for most data-elements eases this tedious task. Searching for experiments and didactic components using the collected meta-data is similarly a functionality offered by the portal. The components for editing, sequencing and retrieving content are discussed in more detail in section 4.

The meta data set here is based on a preliminary GOLC specification that is still under active development; it contains, amongst other data, information on the scientific field, the target user group and a list of keywords. The LiLa ontology and metadata set is described in more detail in [8].

3. The LiLa Architecture

The core of the LiLa architecture consists of a web server running the LiLa portal and a database for keeping the experiments, and a second database for the booking and reservation time slots and the corresponding booking and reservation codes. Experiments are, as already described earlier, represented by SCORM packages, where such a package consists basically of a HTML page providing access to the experiment, metadata annotating the experiment plus all necessary resources to render the page. Such resources are, for example, JAR files for virtual labs that implement the simulation, Labview plugins to gain access to remote experiments or any other mechanism designed by the content creator to reach for the lab.

While not provided by LiLa itself, but rather the LiLa or GOLC community, the back-end servers setup by the content providers to remotely control experiments are of course central to the architecture. How exactly this back-end communicates to the plug-in or front-end in the SCORM package is entirely up to the content provider and left entirely undefined by LiLa. This communication may be SOAP based as in iLabs, it may also be CORBA-based as in VideoEasel[9] (one of the labs provided by Stuttgart), or it could be completely proprietary as for LabView.

The fourth component of LiLa is the LMS (Learning Management System). Though it is not strictly a part of LiLa, it yet plays the vital role of the access point for students. The LMS communicates to the LiLa SCORM packages through the standardized SCORM interface based on JavaScript and, by this way, collects information on its user. Depending on whether the user, i.e. the student, holds a valid reservation for the experiment, the SCORM package rendered by the LMS opens access to the backend experiment, or presents a form allowing the user to book the resource.

This access or redirection functionality, however, is not part of the initial SCORM uploaded by the content provider as it would unnecessarily complicate the process of content creation. Instead, content providers upload a bare-bone SCORM whose purpose is only to grand direct access to the experiment in question. Upon download from the portal by the teacher, this SCORM package is unpacked and re-wrapped by the access layer that contains the code to get user information, i.e. the user identity, from the LMS. This access layer then checks with the booking system database whether the corresponding user holds a valid reservation, or a *stamped ticket* as the LiLa system calls it. Only then the content originally uploaded by the teacher is made available to the user.

While this mechanism is quite elegant and entirely independent on the technology used to remote-control equipment, it is not entirely based on secure protocols, and as javascript *on the user side* is necessarily involved through the mechanisms defined by SCORM, this protocol can be fooled into granting access by advanced javascript hacking. To close this loophole, content

providers *may* optionally include a second check with the LiLa booking database once a connection comes in. To this end, the booking database provides a public interface of its own that may be used by the content provider to validate an incoming connection.

4. Content and Ontology

As briefly discussed in section 3, LiLa aims to be more than a repository of experiments alone; the successful employment of virtual and remote experiments in lectures also requires didactic knowledge and background besides the purely technical access to hardware resources. For this purpose, LiLa *content* consists not only of so called *Access Packages* that implement all necessary technical components to use an experimental resource remotely from a web-browser; it also consists of *Media Packages* that annotate and enrich experiments, i.e. in the simplest case by text documents, but also video and audio files. This *raw* content is, by construction, bare of any didactic purpose, and is orchestrated into *Activities* which are the smallest elements, or atoms, that have a didactic goal. A typical lesson element would group an access package to a hardware resource – or a *Rig* as it is called by GOLC and LiLa – together with an assignment, coming in the form of "traditional media", where the text explains which type of experiment to perform on the hardware, which data had to be measured, and which effect should be observed.

Activities form the components of, for example, homework assignments for students. While such assignments are typically implemented in a Learning Management System, their purpose in the portal is rather to provide use cases how experimental resources are possibly used, i.e. they allow teachers to exchange ideas on the deployment of the material they find on the portal.
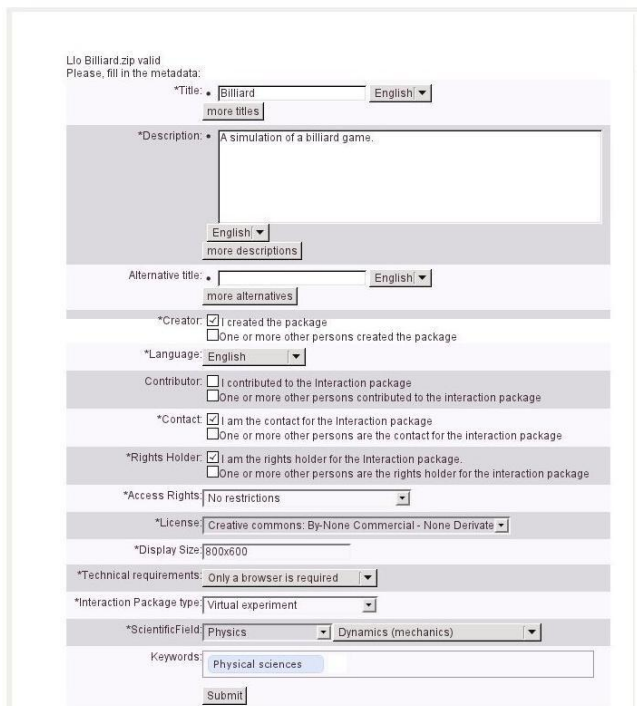
Even though not yet completely implemented, we also aim at providing a "learner support system" that furthermore orchestrates activities into *Lessons*, where a Lesson is a (not necessarily linear) sequencing of activities. It should be noted, though, that a *lesson* is still a small element that might represent one exercise in a homework, and not at all a full lecture, though an element that consists of a series of tasks students need to work through.

In our current deployment of LiLa material, sequencing of activities is still done manual within the learning management system and not the LiLa portal; here a "lesson" consisted of a orientation, execution and review phase; for more information on our didactic approach, see section 6. Later versions of the LiLa portal will provide technical means to support the construction of such lessons.

4.1 Indexing and Retrieval

As the primary purpose of the portal is to aid teachers for optimal deployment of remote and virtual experiments, it is of course also necessary to *find* the material suitable for a lecture, and thus to provide indexing and searching functionality. This comes with the necessity to annotate the resources – experiments, hardware, media, activities and lessons – by meta-data, and to collect this meta-data.

The meta-data set is here a subset of the dataset developed by the members of the GOLC [8], and goes back to the set proposed in the Lab2Go project [5]. Experiments are, within this set, for

example classified according to PACS [16], a scheme mostly used by libraries for indexing books. This is because a long-term goal of the LiLa initiative is to allow library catalogs to reference interactive online material as found in the LiLa portal, and elsewhere.

As the creation of meta-data is a tedious task, the LiLa meta-data editor, see Figure 2, provides useful defaults for most data elements, and derives the defaults from knowledge available otherwise. For example, the default content provider and the default rights owner are identical to the person who is uploading the content, and this data is available from the log-in process. Similarly, the default license conditions for the content is a "Creative Commons" license; more details on the license models on LiLa content will be discussed in the following subsection, though. In addition this meta-data, an content uploader is also requested to provide a list of free-form keywords under which content can be located later on.

FIGURE 2: THE META-DATA EDITOR OF THE LILA PORTAL

Even more important than indexing of content is its retrieval as the primary purpose of LiLa is sharing of experimental resources and didactic material around them. Similar to indexing, searching for content can be tedious if the request is complicated, and most users are overwhelmed by a search mask that offers too many functionalities at once. The portal thus defaults to offering a simple search mask that simply scans for matching terms in the title of the search, see Figure 3. An advanced search mask is available on request, and then allows the user to restrict the search, say, to a specific scientific field, exclude experiments that are not available under a royalty-free basis, and so on.

FIGURE 3: THE SIMPLE SEARCH IN THE LILA PORTAL

All found matches are presented in a list (see Figure 3 again), which allows the user to browse the found content immediately. As the LiLa portal includes a SCORM player, interactive material such as experiments can also be tested online immediately.

4.2   Licensing

Designing and maintaining remote experiments does not come for free, and even providing computer power for simulations requires some investment from the hosting institutions. Thus, users can in general not expect to retrieve all content available LiLa free of charge. For that, the meta-data elements recorded by the LiLa portal upon upload include the rights-holder on the resources, as well as a contact point for maintenance and administration.

A complete discussion of licensing options for commercial content within LiLa is beyond the scope of this article, but has been discussed full detail in [17]. The current default policy offered by the meta-data editor is a Creative Commons License that allows free sharing of content and only restricts commercial use and derivative works [18]. We expect (and promote) that content provides prefer free open access licenses, at least for virtual experiments and simulations, though may derive from them for the reasons given above.

5.   Reservation and Booking

A complete description of the booking procedure of LiLa resources is also outside the scope of this paper, more details can be found in [10]. Roughly, however, booking is a three-stage process: In the first stage, resources uploaded to the LiLa portal by content providers are *reserved* by teachers or institutions. In the second stage, teachers or institutions break up the reservation periods into individual time slots and assign these to lectures. In the simplest possible case, a reservation is used entirely by a complete lecture. In the third step, students of such lecture book experiments for smaller booking periods.

As said, the first stage process breaks up the entire available time on the device into reservation slots within which the device is exclusively accessible by the reserving institution. To this end, the content provider hands out a *reservation code* to teachers or representatives of institutions that requested access. Negotiations on the availability of such devices are handled out of line and are not part of the LiLa portal functionality.

In the second step, a teacher breaks up the reserved time slot on the device into booking slots and assigns to each booking slot a *booking code*. This way, a teacher or institution might use a reserved device for two or more courses in a time-sharing way, where each course is identified by a unique booking code. *Booking codes* are again communicated to students outside the LiLa portal functionality, let it be by either announcing them in the LMS itself, or by posting them on the blackboard in the lecture.

While each reservation is specific to a particular device, a single booking code may make several devices accessible, depending on the schedule of a lecture. A booking code thus represents the right to use one or several devices in time slots assigned by the teacher during an entire course; each booking thus lies within the times within which a specific device has been reserved for the booking institution.

A student approaching a SCORM package in an LMS for the first time will be requested to enter the booking code. This booking code, plus the student identity available from the LMS then creates an entry in the booking data base called *a ticket*. Tickets are valid for the duration of an entire course, and encode the knowledge of the system that the given student identity is part of the course identified by the booking code.

Despite encoding the membership in a course, a ticket also represents the right to book an experiment, very much like a train ticket represents the right to ride a train. That is, once the booking code has been verified by the booking database, the SCORM package within the LMS renders a user interface showing the time slots within which the device would still be available and is not booked by any other student. Once the user selects a time slot, the *ticket* is *stamped*, that is, the selected time slot is marked on the ticket − or linked to the time slot in the booking database. A *stamped ticket* is revoked and no longer valid for booking, very much like a stamped train ticket is no longer valid for riding a second train.

Students now *redeem* reservations by browsing the SCORM package within the LMS again; if the access lies within the booked time period, access is finally granted and the student may now perform the assigned experiment. After this period, the stamp is removed, and the ticket is available for further booking.

However, the booking process offered by LiLa is a service content providers may or may not use. If desired, they may encode their very own booking mechanism in the SCORM package to be uploaded, signal the LiLa system that no booking *through LiLa* is required, and then handle all the booking procedure by themselves.

Furthermore, teachers may also provide more than one booking code to their students, thus granting them the right to book two or even more experiments simultaneously.

6. Experiences and Deployment

Experiments from the LiLa repository have been first deployed in an undergraduate "Experimental Physics for Engineers" course taught at the University of Stuttgart in the winter semester 2009/2010. Later on, the course was revisited and enriched in the next year's lecture when some minor adaptions and modifications were made. As already discussed in section 2, students themselves did not made contact with the LiLa portal itself, but run all experiments through the Learning Management System at the University of Stuttgart, which is ILIAS [11]. First experiences on deployment of LiLa content in this lecture have already been communicated in [15].

The experiments used in this course come from several sources, amongst them are the PhET virtual laboratories of the University of Colorado[12] which can be made available through LiLa due to the open license policy of the University of Colorado; remote experiments from the Remote Farm of the TU Berlin made available through the cooperation in LiLa[13]; the VideoEasel virtual lab[9] of the University of Stuttgart, and experiments from the Cinderella virtual Lab of the PH Karlsruhe/TU München[14]. The latter group is not a member of the LiLa network, but experiments were generously made available by the corresponding authors.
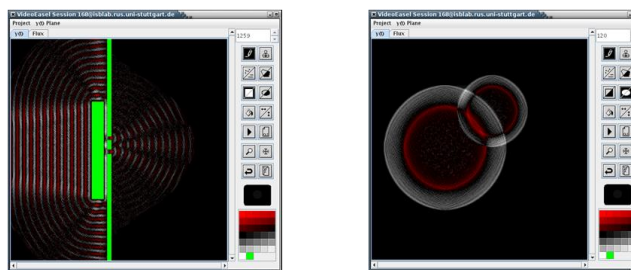

FIGURE 4: AN EXPERIMENT ON THE WAVE EQUATION IN VIDEOEASEL. LEFT: THE DOUBLE SLIT EXPERIMENT. RIGHT: LINEAR SUPERPOSITION OF WAVES.

6.1 Initial Situation

"Experimental Physics for Engineers" is a first year freshmen course taught to all engineering students, including mechanical engineering, aerospace engineering and many others. Typically about 1300 students are attending the course. Due to the high number of participants and limited room capacity, the same lecture is given twice a day, giving all students a chance to attend. The curriculum does not include any mandatory exercises for this specific lecture, nor does the tight schedule allow an accompanying lab course. This has to be taken after the exam of the theoretical part of the course during which the students get no hands on experience. However, our experience is that students participating in the optional homework exercises have a considerably higher chance of passing the final written exam. To motivate students and to make them aware of the importance of the exercises, such positive experience is communicated in the lecture, and optional pen-and-paper exercises are made available in the Learning Management System of the University of Stuttgart. However, until recently, hands-on lab courses have not been part of these optional homework exercises. The aim of the first pilot study in winter term 2009/2010 was to offer students LiLa content as learning alternatives to the pen-and-paper exercises [7].

An initial questionnaire established a first ground on the motivation and interests of the students in remote and virtual experiments and helped to determine their available time. We found that more than 80% of the students were interested in

participating in optional exercises; more than one third claimed to be willing to spend 60 to 90 minutes for them.

6.2 Course Concept

As already stated in section 3, LiLa content is based on SCORM packages and thus integrates nicely into the already established ILIAS Learning Management System [11] of the University of Stuttgart. Offering access to experiments in ILIAS is one matter, developing a didactical concept how to use them, is a different one.

We developed a structure which separates the exercise into three different phases:

1. *The orientation phase:* This first phase allows students to familiarize themselves with the online-experiment. To this end, an abstract on the experiment is presented including a short description of the experiment and the task to perform. Learning goals are described in this phase and a small pre-test evaluates the knowledge of the students before they run the exercises with online-experiments.

2. *The execution phase:* This is the main phase of the exercise. Here, the given task should be mastered by the students using the online-experiment.

3. *The review phase:* In this phase the progress of the students will be checked. This phase is also implemented as a small test.

At the end of the term, we offered an additional exercise with open-ended question that had the following procedure:

1. Unlike former experiments, the task was formulated as an open-ended question. In this first test, we asked "If round objects are thrown into a lake, round waves develop. What happens with square objects? Do you see square waves? If not, please setup an experiment that tries to explain why." Here we expected students to setup experiments to demonstrate Huygen's Principle [15]. Figure 4 provides some screenshots on the wave equation experiment.

2. To allow experimentation, we offered students a virtual laboratory running a simulation of the wave equation. This experiment was based on the simulation framework of the University of Stuttgart [9].

3. Students were asked to write a short report on their results explaining the theoretical background, describing the experiment they set up and how this experiment gaive an answer to the open-ended question.

4. Each participant was asked to correct and evaluate the documents of his/hers peer students. For this step, we provided criteria (like correctness, completeness etc.) for evaluating the reports. They could give up to ten points for each criterion.

5. Based on the final scores of the reports, a winner would be selected.

We were very fond of the exercise and offered it at the end of the term. But unfortunately at this point the students ran out of time due to the upcoming finals and eventually only one out of 1300 students participated in this exercise.

6.3 Results of the Second Year Evaluation

While the results of the first year evaluation have already been reported in [7], we offered a similar course in the winter term 2010/2011. For this course, we made some small changes in the structure of the exercises based on the results of the questionnaires, particularly with regard to the comments and wishes of the students collected in the first year:

- The orientation phase includes now a small interesting and entertaining movie the aim of which is to prepare students for the upcoming exercise and to pique their curiosity.

- The execution phase remained mostly unchanged, though we tried to extend it by including more than one experiment per session. This offers more variety and makes the exercise more interesting.

- The questions of the post-test were now more exam-oriented, stressing their relevance for the exam closing the semester. We originally considered this change to be an additional motivation for performing experiments during the lecture period.

In the following, we will discuss results of the winter term 2010/2011 in comparison to that of the previous year. Tables 1 and 2 show the number of participants per exercise per year:

Exercise	Pre-Test	Execution	Post-Test
1	325	245	153
2	203	173	115
3	133	50	15
4	21	1	no post test in this exercise

TABLE 1: NUMBER OF PARTICIPANTS IN THE EXERCISES IN THE WINTER TERM 2009/2010

Exercise	Pre-Test	Execution	Post-Test
1	801	692	583
2	631	549	463
3	515	414	314
4	478	362	291
5	418	307	238
6	426	281	206

TABLE 2: NUMBER OF PARTICIPANTS IN THE EXERCISES IN THE WINTER TERM 2010/2011

It is important to note that the number of participants **during** the lecture period was much lower than the year before; however, user numbers **exploded** during the spring break two weeks before the exam, and the numbers in Table 2 are the cumulative user numbers including this period. Obviously, students used the online experiments to get prepared for the exam, but not as regular learning material during the lecture period.

Another interesting result of the second year is that now students feel much more supported in exam preparation. This is depicted in Figure 5:
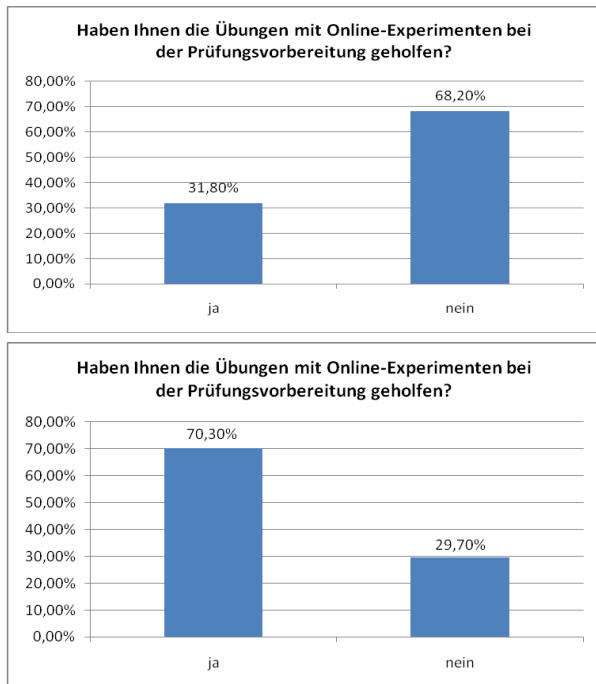

FIGURE 5: DID THE EXERCISE WITH ONLINE-EXPERIMENT HELP FOR PREPARING THE EXAM? LEFT: YES. RIGHT: NO, ON TOP FOR THE PILOT COURSE 09/10, BELOW FOR THE COURSE 10/11.

6.4   Lessons Learned

We found that it is very difficult to get a feeling for "good" online-experiments and "good" exercises on them. We also believe that our colleagues from the physics department probably lacked this insight in the pilot phase, but we noticed that preparing more and more online-experiments increased their experience and exercises gradually improved a lot over the years.

Nevertheless, we should acknowledge that most lecturers will likely face similar problems; for that, we need to build a pool of useful and well-tested experiments and guidelines for teachers on how to deploy them in lectures. Examples drawn from courses which already use experiments will definitely be very helpful.

In 2009/10, we noticed that the participation decreased with the exams coming closer: As a consequence, we changed the layout of the lecture and the experiments a bit and offered the advanced experiments earlier in the year. We also increased the relevance of the exercises for the exam. This fact was explicitly pointed out to the students.

The content of an exercise should always be discussed in the lecture before the experiment becomes available online. Students remarked a "very high demand" if that was not the case. In the second year this was no longer an issue because we improved the synchronization between the lecture and the exercises.

The winter term 2010/2011 saw a very vivid use of the forum in the LMS. Students were discussing their results, explained the way they got them, and reflected their approaches. During the preceding summer term the lecturer had provided solutions for the exercises and the forum was remained unused. In the winter term, in contrast, the lecturers and his tutors commented on the students' discussions where necessary in the forum. It is expected that with the more profound reflection of the problems the learning outcome of the students is better.

Around 29% of the students mentioned technical problems in the pilot winter term 2009/2010 and, as said, these problems drove them off. Also, the usability of some experiments required improvement. We are working on these problems and hope to have removed at least some of the technical and usability obstacles. In the winter term 2010/2011, only about 21% of the students mentioned such problems, though we noted that the reported problems were different from those reported the year before. For example, the students now mentioned that they had problems with loading or starting experiments, the connection was to slow or the experiment was not coming up in time. Possibly the increasing number of students caused capacity problems for some of the designs, so we might have to reconsider them.

The fact that the work load in the first semester is quite high is unfortunately beyond our influence, and we cannot reasonably address this problem in short term.

7.   Discussion and Conclusions

After the first two years we can say that exercises with online-experiments are a good and motivating addition to lectures. While we originally designed the exercises to be used as supporting material for the lecture itself, students seem to prefer to use them as preparation for the exam. Most of the students are interested in doing such exercises and they commented positively on the available experiments. The biggest problem is still lack of time due to the tight schedule. As long as these exercises remain optional and voluntary this problem will persist. We should try to make the experiments and exercises "cool" to catch the curiosity of our students.

Other problems which arose in the pilot phase are issues which can be corrected by improvements of the exercises and experiments themselves, such as working on technical or usability issues, adding further information to the exercise tasks, adding solutions and hints how to solve them. After the pilot phase we already did some of these improvements and which had positive effects. But, as always, other problems and challenges will appear and will require continuous improvements of our setups.

8.   ACKNOWLEDGEMENTS

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